

The first spectroscopic verification of an extragalactic classical chemically peculiar star

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ABSTRACT

We present the first spectroscopic verification of a bona fide chemically peculiar (CP) star in the Large Magellanic Cloud. CP stars reside on the upper main sequence and are characterized by strong global stellar magnetic fields with a predominant dipole component oriented at random with respect to the stellar rotation axis and displaced from the stars centre. Overabundances with respect to the Sun for heavy elements such as silicon, chromium, strontium and europium are also a common phenomenon. These objects are excellent astrophysical laboratories by which to investigate many of the processes connected with star formation and evolution. Several studies comparing the incidence of CP stars in the Large Magellanic Cloud with that of the Milky Way have been published. These investigations are based on the photometric detection of CP stars via the Δa system which has been tested and calibrated for objects in the Milky Way. From our spectroscopic observations made at Las Campanas Observatory, we are able to confirm one classical B8 Si star among the photometric sample, as well as one early B-type emission-line star which was also initially detected by its significantly deviating Δa value. We conclude that classical extragalactic CP stars do exist and that the photometric Δa system is able to detect them in an efficient way.

Key words: Stars: chemically peculiar – stars: early-type – stars: emission-line, Be – Magellanic Clouds, open clusters and associations: individual: NGC 1866 Magellanic Clouds.

1 INTRODUCTION

The group of chemically peculiar (CP) stars of the upper main sequence display metal abundances that deviate significantly from the standard abundance distribution (Asplund et al. 2009); a subset of this class, the CP2 stars (Preston 1974), reveals the existence of strong global stellar magnetic fields (Cowley, Hubrig & González 2009). In addition, this subclass of B to F-type stars is characterized by radial velocity changes as well as photometric variability due to stellar rotation and a spotty surface structure.

The origin of the stellar magnetic fields is still not resolved. Several recent publications (e.g. Hubrig et al. 2009) favour a model in which they are the survivors of frozen-in fossil fields originating from the medium out of which the stars were formed. During the main sequence evolution, a

dynamo mechanism may act in the interior of these stars, enhancing the field strength.

One of the most important key parameters for our understanding of star formation and evolution is the intrinsic metallicity of (proto-)stars of a given mass. Even in the early stages of stellar evolution, the metallicity severely influences the cooling and collapse of ionized gas (Jappsen et al. 2007). With this fact in mind, by investigating CP stars in the Magellanic Clouds, we are able to assess the degree to which the presence or nature of chemical peculiarities is governed or influenced by initial metallicity. Moreover, by such studies we may be in a position to determine whether different magnetic field strengths in the region of star formation lead to the same frequency of magnetic stars. The incidence and characteristics of CP2 stars are already well investigated in the Milky Way (Netopil et al. 2007).

Due to the typical flux depression in CP stars at λ 5200Å, the tool of Δa photometry is able to detect them in an economical and efficient way by comparing the flux at the centre (5200Å, g_2) to the adjacent regions (5000Å, g_1 and 5500Å, y). It has been shown that virtually all pecu-

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† This paper includes data gathered with the 6.5 meter Magellan Telescopes located at Las Campanas Observatory, Chile.

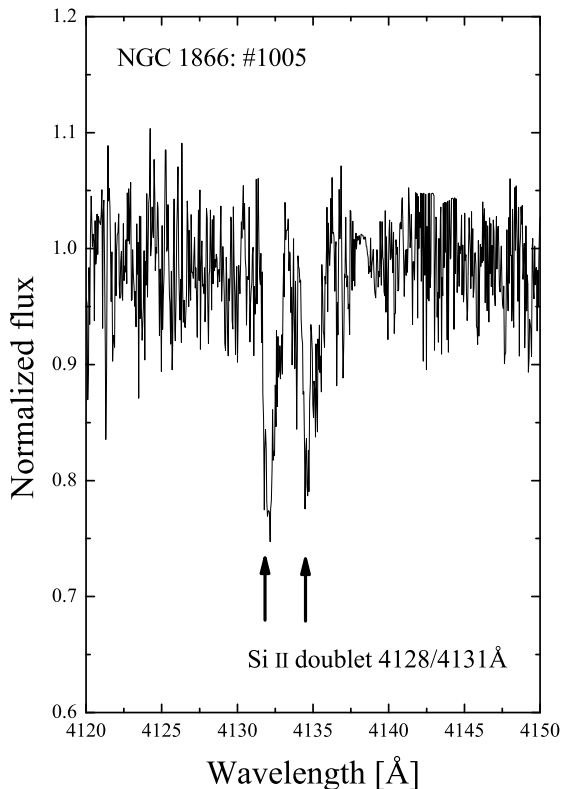


Figure 1. The Si II doublet detected in star #1005. The spectrum has been shifted to the rest frame of the Sun. To within the measurement uncertainties ($\sim 15\%$), the equivalent width of each line is the same, viz. 0.30 Å .

liar stars with magnetic fields have significant positive Δa values of up to $+100 \text{ mmag}$ whereas Be/Ae and metal-weak stars exhibit significantly negative ones (Paunzen, Stütz & Maitzen 2005).

Since the first detection of photometric CP candidates by Maitzen, Paunzen & Pintado (2001) in the Large Magellanic Cloud (LMC), several other studies, summarized in Paunzen et al. (2005), significantly improved the observational evidence that the incidence of these stars is much less than in the Milky Way.

However, all these investigations are based on one important assumption: classical CP stars do exist in the LMC and are unambiguously detected by Δa photometry.

In this paper, we present the first spectroscopic verification of one bona-fide photometric CP star candidate in the LMC on the basis of the strong Si II doublet at $4128/4131 \text{ Å}$. In addition, we are able to confirm the emission feature of one object found to exhibit a significant negative Δa value. These results compare well with those of Galactic investigations of the same kind (Paunzen, Stütz & Maitzen 2005).

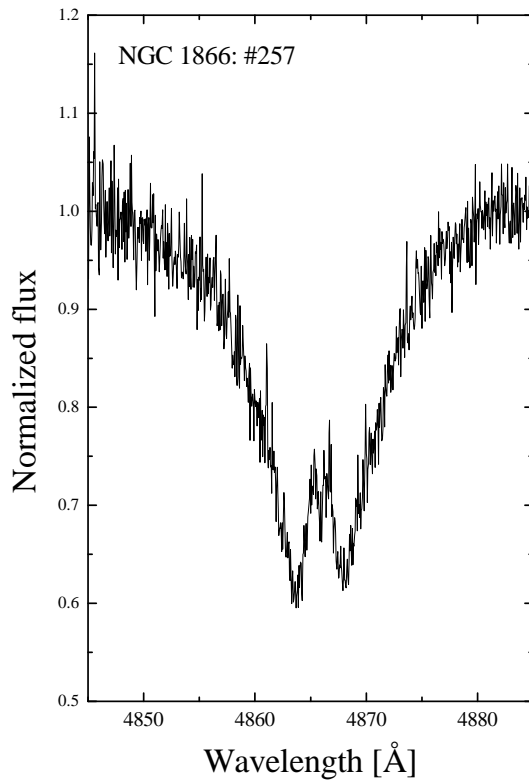


Figure 2. The emission structure of $H\beta$ in star #257 which exhibits a significant negative Δa value. The spectrum has been shifted to the rest frame of the Sun.

2 TARGET SELECTION, OBSERVATIONS AND REDUCTIONS

From the published list of stars given by Maitzen, Paunzen & Pintado (2001) with significant positive Δa values, we chose the CP candidates #687, #1005, and #1093 (the numbering system is adopted from the aforementioned reference). In addition, the metal-weak/Ae/Be/shell candidate #257 was selected for our study. The V magnitudes of the targets, all located in the field of NGC 1866, are between 16.9 and 18.2 mag, near the limiting brightness for achieving usable spectra in moderate exposure times with the instrumentation available.

The observations were performed with the Magellan Inamori Kyocera Echelle (MIKE), a high-throughput, double echelle spectrograph (Bernstein et al. 2003) on the 6.5-m Magellan telescope (Clay) at Las Campanas (Chile) on the nights of 18-20 November 2004 by one of us (DJB). The spectrograph employs a dichroic filter with separate blue and red fibres to provide simultaneous coverage of wavelengths spanning the range from 3200 to 10000 Å with a typical one-pixel resolution of 0.04 to 0.05 Å . The spectra were binned 2×2 to produce a resolution of about 0.08 Å in the blue. This value comports well with the measured half-widths of sharp, unblended comparison lines in the ThAr spectrum near 4000 Å which yields on the average 0.12 Å . Integration times between 30 and 60 minutes were chosen

to control the intensity of the night sky lines and to limit spectral contamination from neighbouring stars in crowded fields caused by rotation of the slit on the sky.

All reductions were performed with standard IRAF routines¹. After the bias, dark and flat field corrections, the spectra were wavelength calibrated (including a heliocentric correction) using two ThAr standard spectra observed before and after the corresponding target. As a final step, the spectra were co-added to increase the signal-to-noise ratio.

3 RESULTS AND CONCLUSIONS

Due to the faintness and the high spectral resolution of the instrument, the signal-to-noise ratios of the final spectra are very low, typically around 15. For the bluest and reddest regions of the spectra, no signal at all was observed because of the drop of the quantum efficiency of the CCDs.

For all stars, the hydrogen lines are the most prominent features in the spectra. The photometric candidates are thus clearly in the expected effective temperature range for classical CP stars and not contaminated by any late-type foreground background objects.

One of the most prominent features of early-type CP stars is the Si II doublet at 4128/4131 Å which is very much stronger than comparable lines in normal stars (Bidelman & Böhm 1955). The enhancement of this doublet is an unambiguous characteristic of magnetic CP stars in general, and so we primarily searched for this feature in the spectra.

For targets #687 and #1093 we were not able to detect any features beside the hydrogen lines due to the low signal-to-noise ratio of the spectra and moderate rotational velocities of the stars. Applying several smoothing techniques (boxcar, FFT, and median) still revealed no additional features above 5σ of the mean noise level. Unfortunately, we are not able to reliably analyze the 5200 Å region because the depths of the flux depressions for the measured Δa values for these stars are too shallow for the low signal-to-noise ratio (Kupka et al. 2004).

The rotational speeds of these two stars can be estimated, however, from comparisons of the observed hydrogen line profiles with synthetic spectra. Establishing a credible continuum level for the hydrogen lines in our echelle spectra is neither easy nor unambiguous, and normalization was carried out using the shape of the flat field function of the corresponding aperture. From different numerical experiments using a range of stellar parameters, we find that the most probable $v \sin i$ values for #687 and #1093 fall within the range of 100 to 150 km s⁻¹.

Figure 1 shows the Si II doublet observed for #1005 with the most significant Δa value detected, 10.8σ above the normality line. We measured the separation of the two lines which is, within the errors, identical with the theoretical one. The spectral feature is so strong that we immediately classify this object as a typical silicon star of the CP2 group. We measured the equivalent widths of the doublet to be 0.30 Å for each line with an error of about 15%. For normal late B-type stars (dwarfs and giants), the corresponding value is

0.19 Å (Jaschek & Jaschek 1995). We notice that the equivalent width of the Si II doublet for dwarfs is at a maximum for spectral type B8 and drops to 0.15 and 0.11 Å for B7 and B9, respectively. The corresponding equivalent widths for late B-type CP stars range from 0.2 to 0.4 Å, depending on the rotational phase and the strength of the stellar magnetic field (López-García & Adelman 1999). These values are in agreement with the measurements of #1005.

Testa et al. (1999) published $V = 17.797(5)$ and $(B - V) = 0.014(13)$ mag for this star. Using the distance modulus of 18.33 and $A_V = 0.25$ mag for NGC 1866 and its surrounding taken from Salaris et al. (2003), we derive an absolute magnitude of -0.8 mag which coincides with a main sequence late B-type star. Within the given errors we classify #1005 as B8Si star. From the original as well as a smoothed spectrum, we determined the upper limit of $v \sin i$ as 50 km s⁻¹ from the hydrogen lines and Si II doublet.

The emission characteristics of H β for star #257, which exhibits a significant negative Δa value at a 10.7σ significance level, is shown in Fig. 2. This object is about 0.7 mag brighter than #1005 which suggests an early B-type. Again, this result is in agreement with the findings for similar stars in the Milky Way.

From the wavelength calibrated spectra (Figs. 1 and 2), using the hydrogen lines, we were also able to obtain estimates of the heliocentric radial velocities for each target star. The final values are between 280 and 320 km s⁻¹ with errors of about 20 km s⁻¹. This clearly establishes them as true members of the LMC and not Galactic foreground objects (Prevot et al. 1985).

With the first spectroscopic verifications of the true natures of photometrically detected peculiar stars in the LMC, we demonstrate the reliability of the Δa system for observations in extragalactic environments. The published photometric CP candidates are therefore excellent targets for follow-up investigations which will help shed more light on stellar formation and evolution in areas with different metallicities and/or different magnetic field strengths. For the latter, no measurements in the Magellanic Clouds are yet available. With new generation telescopes and satellite missions, we anticipate that more distant galaxies in and beyond the Local Group will become accessible for this research area.

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